OVERVIEW---NASA MICROGRAVITY COMBUSTION PROGRAM

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF LIFE AND MICROGRAVITY SCIENCES AND APPLICATIONS (OLMSA)

MICROGRAVITY RESEARCH DIVISION (MRD)

BIOTECHNOLOGY | **MATERIALS SCIENCE** | **FUNDAMENTAL PHYSICS** | **FLUID PHYSICS**

COMBUSTION

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RATIONALE FOR MICROGRAVITY COMBUSTION STUDIES

- Eliminate buoyancy-induced flows and turbulence
- Isolate forces/flows obscured under normal gravity conditions
- Eliminate gravitational settling of particles which tends to compromise studies of dust-cloud combustion phenomena
- Permit study of larger time/length scales in experiments, permitting improved utilization of diagnostics
- Permit study of truly spherical droplet combustion, aiding comparison of data with model predictions in elucidation of basic principles
- Allow quantification of ignition/flamespread characteristics of materials employed in space applications under relevant conditions

Long-term Goals of HEDS Microgravity Combustion Program

- **Meld microgravity combustion space experiments with ground-based studies, using gravity as an added independent variable, to provide better mechanistic understanding and more rigorous testing of analytical models**
- **Utilize basic research to provide technological advances in various combustion processes/devices**
- **Create the understanding that will permit lessons learned in microgravity combustion experiments and modeling to be used in optimization of terrestrial combustion devices**
- **Provide quantum leaps in the areas of fire safety and economical minimization of combustion-generated pollution**
- **Provide the understanding that will permit efficient use of alternative fuels, which will be increasingly needed as we deplete oil and gas reserves**
- **Develop a better understanding of various combustion synthesis processes, opening the doors to production of novel tailored materials here on Earth as well as elsewhere**

Combustion Technology Goals Included in HEDS Roadmap

- Active control over thermal efficiency and pollutant generation through sensor development and miniaturization along with development of control algorithms
- Use of magnetic and electric fields to improve thermal efficiency
- Improved atomization methods for diesel and gas turbine engines through better understanding of liquid jet breakup and droplet interactions in sprays
- Flame-zone pollution control in premixed and diffusion burners via fundamental understanding of flame structures and pollutant formation mechanisms
- Improved exhaust gas monitoring for combustion devices combined with “smart” controls to compensate for fuel variations or combustor component degradation
- New flame stabilization/control technologies for burners enabling reliable ultra-lean premixed combustion through improved understanding of flame stabilization
- Development of improved strategies and procedures for fire prevention, detection, and suppression in microgravity (Space Station) and reduced gravity (Mars, Moon)

Combustion Technology Goals Included in HEDS Roadmap

- Reduction of hazards associated with gaseous fuel combustion through better mapping and understanding of flammability limits and combustion instabilities
- Development of improved protection against large-scale fires through better understanding of material ignition and flamespread phenomena
- Reduction of mine and grain silo explosion hazards through improved understanding of fundamentals associated with these phenomena
- Improvements in hazardous liquid waste incineration through studies of droplet and spray burning and of pollution generation fundamentals
- Development of industrial-scale combustion-generated fullerene production through determination of approaches for improving yields in flame systems
- Production of composite materials with improved properties via better understanding of controlling micro-structural uniformity and porosity
- Development of means for producing and utilizing alternate fuel/oxidizer combinations associated with Lunar, Martian, or other extraterrestrial habitats

Areas of Research Recommended by the Combustion Science Discipline Working Group

- Turbulent Combustion
- Transient Processes in Gaseous Flames
- Soot processes
- High Pressure/supercritical fluid effects
- Spray and Aerosol Cloud Ignition and Combustion
- Combustion Synthesis
- Classical Model Validation & Development of Benchmark Data Sets
- Detailed Measurements of Species Concentration Fields in Various Flames

Fundamental Data Sets

Over-riding Issue: Define what are most important data sets in terms of:

(1) Design

(2) Model Testing

Groups:

Physico-Chemical Constants (e.g., thermal and mass diffusivities at high P and T for various species including intermediates)

Fundamental Combustion Parameters---Not Device Dependent (e.g., Laminar Burning Velocities, Extinction Strain rates, Soot Inception Points, Markstein Lengths)

Classical Well-Defined Benchmark Systems For Model Validation and Calibration----System Dependent (e.g., Flame Spread rates, Burke-Schumann Flame Shapes)

Emerging Topics (Spacecraft Fire Safety, SHS, Flame-synthesized materials)

SAMPLES OF FUNDAMENTAL DATA SETS

DROPLET COMBUSTION

Burning rate Constants Flame Diameters vs Time Flame Diam/Droplet Diam vs Time Extinction Diameters Soot Sheel Size vs Time	As functions of Initial Droplet Diameter, Gas Composition, Fuel Type, Pressure, and Ambient Temperature

SOLID FUEL COMBUSTION

Flame Spread Rates Ignition Diagrams	As functions of Flow Velocity and Direction, Fuel Type, Fuel Thickness, Gas Composition and Temperature, Emissivities, and G-level/Orientation

SAMPLES OF FUNDAMENTAL DATA SETS

PREMIXED GAS FLAMES

Flammability limits	As functions of Temp, Pressure
Laminar Burning Velocities	As functions of Temp, Pressure, Composition, Strain Rate
Markstein Lengths	As functions of Temperature,
Extinction Stretch Rates	Pressure, and
Flame Ball Diameters	Composition

GASEOUS DIFFUSION FLAMES

Flame Shapes	As functions of P, T, Composition
Soot Parameters (Vol Fr, Size, Shape)	of Fuel and Oxidizer Streams
Porous Sphere Flame Size	As functions of these parameters
Porous Sphere Soot Shell Size	and Fuel Injection Rate

TOPICS BEING ADDRESSED IN CURRENT PROGRAM

GASEOUS FLAMES (38)

Premixed	(7)
Diffusion	(17)
Partial Premixed	(2)
Triple Flames	(1)
Flame-Vortex	(3)
Kinetics	(1)
Electric Fields	(2)
Suppression	(1)
Diagnostics	(4)

SURFACE COMB (10)

Flame Spread	(1)
Flammability Test	(3)
Smoldering	(1)
Liquid Pools	(1)

DROPLETS, SPRAYS, PARTICLES, DUSTS (16)

Single Droplets	(4)
Arrays	(2)
Sooting Drops	(2)
Sprays	(1)
Particles	(2)
Dust Clouds	(3)
Bubble Combust	(2)

COMBSYNTH (8)

SHS	(3)
Fullerenes	(2)
Nanoparticles	(2)
Agglomerates	(1)

MISCELLANEOUS (6)

G-Jitter	(1)
Propellants	(4)
Cold-Boundary Flames	(1)

CURRENT PROGRAM MAKEUP

R&A Investigators	58	Mostly 4 year
Flight Definition PI's	6	4 year +
Flight PI's	14	Variable
ATD Projects	2	Generally 3 year
GSRPs	3	3 year
Preliminary Studies		

ANTICIPATED 1999 NRA AWARDS

Flight Definition Awards	0 to 3
R&A Awards	15 to 20

NASA Research Announcement (NRA)

- **Ground based research**
  - + **Provides the intellectual underpinnings of the flight program**
  - + **Experimental and theoretical**
  - + **Well articulated microgravity relevance**
    - **Demonstration of the role of gravity; benefits to be accrued from conducting research in microgravity**
    - **Support for the microgravity materials science program**
  - + **Funding for up to 4 years**
  - + **Average $100k/year**
- **Flight experiments**
  - + **High scientific and technical merit**
  - + **Well articulated need for a long duration, high quality microgravity environment**
  - + **Experimental and theoretical maturity to support a Science Concept Review within approximately two years**
  - + **Average $150k/year**

REVIEW PROCESS STEPS

- Divide proposals into categories, establishing external peer review panels for each category
- Obtain written reviews and ratings (three per proposal) from the reviewers, each of whom review approximately 10 proposals. Each proposal is rated on scientific merit, microgravity relevance, and responsiveness to HEDS goals
- Have meeting with all reviewers for a given panel, to establish consensus view for each proposal. Assign each to "Highly Qualified", "Qualified", or "Not Qualified" categories
- For strong candidates likely to require flight, have feasibility and resource compatibility review done by NASA/Lewis personnel
- Assess program balance issues and develop prioritized list of awards for Ground-Based and Flight Definition Programs (Program Scientist)
- Final decisions made in meeting of Science Branch and approved by Chief Scientist and Division Director

PROPOSAL EVALUATION CRITERIA

- **Is microgravity of fundamental importance to the proposed study?**
- **Do the issues addressed have the potential to close major gaps in the understanding of fundamentals of combustion processes?**
- **Is there potential for elucidation of previously unknown phenomena or interactions between phenomena?**
- **Is the project likely to have significant benefits/applications to ground-based as well as space-based operations involving combustion phenomena?**
- **Are the results likely to be broadly useful, leading to further theoretical or experimental studies?**
- **Can an additional project in the specific subarea being addressed be justified in terms of allocation of limited resources?**

PROPOSAL EVALUATION CRITERIA

- **Is the project technologically feasible, without requirements for substantial new technological advances?**
- **How well will this project stimulate research and education in the combustion area?**
- **How does the projected cost/benefit ratio compare with other projects competing for the same resources?**
- **What is the potential of this project in terms of stimulating future technological "spinoffs"?**
- **Are there strong well-defined linkages between the proposed research and goals of the Human Exploration and Development of Space?**

ADVICE FROM PAST REVIEWERS TO PROPOSERS

- Reviewers appreciate clear and concise writing.
  - Proof read text and use clearly marked figures with appropriate captions.
- Reviewers will not "read between the lines."
  - While they may be familiar with your previous work, they will not assume that you are aware of important issues unless you indicate them explicitly.
  - What specific problems are to be investigated (experimentally or theoretically)? What is the working hypothesis?
- Appendices and supplementary material should be added judiciously.
  - Reviewers appreciate inclusion of publication reprints that report previous results that are key to the success of the proposed work. However, these should be kept to an absolute minimum.

ADVICE FROM PAST REVIEWERS TO PROPOSERS

- Reviewers expect proposals written within the designated guidelines that provide the information required for evaluation.
  - In some cases microgravity relevance is vague or non-existent
  - Length (20 pages)
  - Supporting material (appendices/supplementary material)
  - Budget
- Collaboration: Multiple Proposals vs Long, High Budget Proposals
  - Reviewers typically preferred separate proposals where clear indication was given to collaboration with other proposers.
  - Reviewers indicated that large, expensive proposals were difficult to evaluate.
    - If they were within the length guideline, there was not enough detail concerning each part.
    - If they were outside the length guideline, reviewers saw this as unfair to other proposals that stayed within guideline.

1999 NRA SCHEDULE

• 5th Int. Microgravity Comb. Conf.	May 18-20, 1999
• CBD Announcement	Mid October, 1999
• NRA Release/Mailing	Mid November, 1999
• Letters-of-Intent Due	Early January, 2000
• Proposals Due	Mid February, 2000
• Review Panel Evaluations	April-May, 2000
• Final Selections	August, 2000
• Award/Declination Letters	September, 2000
• Grant/Contract Placement	December, 2000

GROUND-BASED PROGRAMS

- **Single Review Process (Proposal Review Only)**
- **Generally 2 or 4 year program**
- **Include:**

  Theoretical Studies

  Normal Gravity Baseline Experiments

  Drop-tower microgravity experiments

  Parabolic aircraft microgravity experiments

  Possible GloveBox experiments on shuttle

FLIGHT PROGRAMS

- Multiple Reviews (Proposal Review, SCR, RDR)
- Indterminate length as long as successive reviews are passed
- Include:

  All items included in Ground-Based Programs
  Sounding Rocket microgravity experiments
  Shuttle Middeck microgravity experiments
  Shuttle Cargo Bay microgravity experiments (GASCAN)
  Spacelab/Spacehab microgravity experiments
  Mir microgravity experiments
  International Space Station microgravity experiments

FLIGHT PROGRAMS

Flight proposers should make every effort to fit their experiments into the experiment structures currently planned for the International Space Station since estimated total costs associated with developing and implementing the experiments will be a major proposal evaluation factor.

- **ISS**
  - **Glovebox Facility (Microgravity Science Glovebox)**
  - **Fluids and Combustion facility (FCF)**
    - **Combustion Integrated Rack (CIR)**
      - **Droplet Combustion Apparatus**
      - **Multi-user Solid Fuels Apparatus**
      - **Multi-user Gaseous Fuels Apparartus**

These facilities will be described in some detail (dimensions, resources available, etc) in the NASA Research Announcement

Science Concept Review: Charge to the Peer Review Panel

The Panel will assess:

- **Significance of the problem including benefits that the experimental and theoretical results will provide to the combustion science research community and industry**
- **The maturity of the overall scientific investigation**
- **The scientific objectives of the proposed flight experiments**
- **The need for a microgravity environment to achieve the proposed science objectives**
- **The priorities of these science objectives**
- **The rigor with which the proposed flight experiment has been defined and scoped by supporting ground-based research**
- **The scientific specifications for the proposed flight experiments as expressed in the preliminary draft of the Science Requirements Document**
- **The conceptual design for the apparatus and whether this design can be expected to deliver a level of performance allowing the science objectives to be achieved.**

Requirements Definition Review: Charge to the Peer Review Panels

Objectives of the Requirements Definition Review:

- **Review the final science requirements.**
- **Reassess the need for microgravity.**
- **Review and assess issues/recommendations from SCR Panel Report**
- **Assess the engineering feasibility.**
- **Assess the project planning.**

Science Review Panel:

- **Assess the final science requirements.**
- **Reassess the need for microgravity.**
- **Assess whether the science requirements can be met by the hardware capabilities as reflected in the engineering requirements.**

Engineering Review Panel:

- **Assess how engineering requirements comply with science requirements**
- **Review the hardware design.**
- **Review the payload carrier accommodations.**
- **Review the Project Plan**

Documents/Websites of Interest

FY1998 Microgravity Science Taskbook------NASA TM XXXX. Available on Web at: http://peer1.idi.usra.edu/peer_review/taskbook/micro/mg98/mtb.cfm

NASA/Lewis Website------Includes Information on Facilities, Experiments, Educational Activities, Missions, Services, Etc. Available on Web at: http://zeta.lerc.nasa.gov

Microgravity Combustion Science:1995 Program Update------NASA TM 106858. Available from Merrill King (202-358-0817) or Howard Ross (216-433-2562)

NASA Microgravity Combustion Research Program as of November,1998. Available from Merrill King (202-358-0817)

NASA/OLMSA Research Opportunities Available on Web at: http://peer1.idi.usra.edu